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GAS-TUNGSTEN-ARC WELDING OF INCONEL 625 FOR IRRADIATED NUCLEAR FUEL WASTE DISPOSAL CONTAINERS

Report No 86-147-K

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ABSTRACT

It has been demonstrated that the gas-tungsten-arc welding process is readily applicable to the final closure of Inconel 625 thin-walled irradiated nuclear fuel waste disposal containers. Sound welds were produced in the 2G welding position (container vertical) which displayed good mechanical properties without the use of a backing gas shield.

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EXECUTIVE SUMMARY

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As part of Ontario Hydro's technical assistance to the Canadian Nuclear Fuel Waste Management Program, a welding procedure was developed by the Welding Unit of the Metallurgical Research Department, for the final closure of thin-walled Inconel 625 nuclear fuel waste disposal containers.

It was shown in the present work that sound welds in Inconel 625 plate (~7-mm thick) can be made consistently in the 2G (container vertical) position using the gas-tungsten-arc welding process. A four-pass procedure was used in a single-vee-groove design with integral backing. A thick top (>13 mm) lid is recommended with this joint design to eliminate the need for internal or back side gas shielding.

The mechanical properties of the Inconel 625 welds were similar to those of the base metal in terms of ultimate tensile strength and hardness. No grain boundary carbide precipitation that would reduce corrosion resistance was found in the weld heat-affected zone.

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To Mr. H.N. Isaac
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GAS-TUNGSTEN-ARC WELDING OF INCONEL 625 FOR IRRADIATED NUCLEAR FUEL WASTE DISPOSAL CONTAINERS

1.0 INTRODUCTION

As part of Ontario Hydro's technical assistance to the Canadian Nuclear Fuel Waste Management Program, a welding procedure for the final closure of thin-walled (∿7-mm thick) Inconel 625 irradiated fuel waste disposal containers is to be developed by the Welding Unit of the Metallurgical Research Department. Inconel 625, a nickel-chromium alloy, is one of the candidate materials being evaluated for the fabrication of these containers/1/. Previous work has shown that this alloy is weldable with the electron beam welding process/2/, but resistance-heated diffusion bonding has been shown to be unsuitable for joining 6.4-mm thick Inconel 625 plates due to the rapid formation of an oxide film in the bond area/3/.

This report deals with the development of a mechanized pulsed-current gas-tungsten-arc welding (GTAW) procedure for the 2G (weld horizontal) welding position. A suitable weld joint configuration was identified and metallographic and mechanical testing of the welds was carried out.

2.0 TEST EQUIPMENT AND TECHNIQUES

2.1 Materials

The Inconel 625 hot rolled plate material was specified to ASTM B-443 in 6.35-mm (1/4 inch) thickness. The actual thickness of the as-received plate was 7.2-mm. The chemical analysis of the heat of this plate is given in Table I.

The welding filler metal used was Inconel Filler Metal 625 in 1.14-mm (0.045 inch) diameter. This material meets the requirements of ASME SFA 5.14 as ERNiCrMo-3 bare wire welding filler metal. The chemical analysis of this particular heat is given in Table I.

Each weld joint was prepared to a specified joint design (see Figure 1) by milling the plate edge and removing burrs and scale using a light grinding. The plates were then degreased, cleaned and tack-welded to a backing plate to simulate the integral backing design of the specified joint. Strong-backs were used to simulate the high restraint on the weld that is inherent with this joint design.

2.2 Welding Equipment

A Dimetrics Gold Track II Pipe Welding System was used for the welding procedure development. This system consists of a pulsed-current Gas-Tungsten-Arc welding (GTAW) power source with controls for a mechanized pipe-welding head. The functions of this head include automatic voltage control of arc length, pulsed filler-wire feed, torch travel and torch oscillation control. The welding head was mounted on a straight track for horizontal welding of the test plates, which were clamped in place.

2.3 Weld Quality Evaluation Techniques

Each weld was visually examined for surface appearance and proper fill height. Cross-sections were also prepared from the welded samples for metallographic examination.

Mechanical testing of the welds consisted of Vickers hardness testing of the weld cross-sections and tranverse tensile testing of a completed weld joint.

3.0 WELDING PROCEDURE DEVELOPMENT

3.1 Joint Design

The welding joint design selected is basically the same as the one used in similar welding procedure development work being done at Ontario Hydro Research for titanium thin-walled containers/4/. This design consists of a V-groove with a 45° included angle, and a 4-mm root opening with backing (see Figure 1). For the integral backing design, it was found from the previous work that for titanium, a thick top lid is required to provide sufficient metal thickness above the weld joint so that the capping pass can be performed without melting the top edge. In addition, the top lid thickness requirement was estimated to be >19-mm to provide a massive heat sink effect to help control air contamination. However, for Inconel 625 this thickness could be reduced to perhaps $\sim$13-mm as the heat sink effect will not be required.

3.2 Welding Procedure

The optimized GTAW procedure developed for the final closure of thin-walled titanium containers/4/ was used to develop a suitable GTAW welding procedure for Inconel 625 containers. Details of the welding procedure are shown in Table II and the fill pattern of the groove is illustrated in Figure 2.

All the welding trials were performed on 7.2-mm thick plates. However, the procedure developed will be suitable for Inconel containers with wall thicknesses in the range of $\sim$ 4 to 7.2-mm with some modifications. The weld consisted of four layers, each layer comprising a single weld pass. The capping pass employed a weaving pattern to cover the required weld width. This reduced underfill or undercutting near the weld edges. Prior to the capping pass, a mode that slaved current pulsing and wire-feeding to the torch oscillator was selected on the power source. In this mode, high pulse current and wire feed were used only during the dwell periods at the sides of the weld groove to ensure sidewall wetting and fusion. During the excursion time between the dwells the low pulse parameters were used to ensure a flat profile. Weld sag by gravity could be prevented by selecting the proper dwell times (i.e., long dwell time on the upper side and short dwell time on the lower side of the horizontal weld joint). Details of the capping pass welding parameters are shown in Table II.

As with all GTAW procedures, a slope-down of weld current is required at weld termination to avoid crater cracking due to a sudden arc stop. A slope-down time of about 20 seconds was required for the Inconel GTAW procedure.

3.3 Metallographic Examination & Mechanical Testing

3.3.1 Surface Appearance: The surface appearance of the capping pass is shown in Figure 3. The weld surface was generally quite smooth and the total width is approximately 10 to 11 mm.

3.3.2 Metallography: Several weld cross-sections were prepared for metallographic evaluation; a typical example is shown in Figure 4. The maximum reinforcement height (or weld cap height) was 0.7-mm. The root penetration in the example was 0.7-mm and the root width is 3.0-mm. No porosity nor cracking was visible in any of the cross-sections and no sensitization (grain boundary carbide precipitation) was detectable in the heat-affected zone.

3.3.3 Hardness Testing: The weld cross-sections were tested for Vickers hardness using a 2.5 kg load. No significant differences were discovered among the various weld regions and the base metal. All areas, including the weld metal, heat-affected zone and base metal, had an average hardness in the range of 196 to 207 Vickers points.

3.3.4 Tensile Testing: Two tensile test coupons were prepared from a sample welded with the finalized procedure. Satisfactory ultimate tensile strength across the weld joint was achieved, (see Table III). From ASTM B-443, the requirement for base metal ultimate tensile strength is 827 MPa (120,000 psi). Both of the tensile-test specimens exceeded this minimum requirement; one failed at 859 MPa (124,600 psi), the other at 837 MPa (121,400 psi). In both specimens, the fractures were ductile and were located in the weld metal.

4.0 DISCUSSION

4.1 Welding Procedure

We have demonstrated that a sound mechanized GTAW procedure can be established easily for 7.2-mm thick Inconel 625 plates and are confident that this procedure can be readily modified to produce a final closure weld on an Inconel container with a wall thickness in the range of 4 to 7.2-mm. The procedure would require adjustment to account for equipment differences and exact geometry (including misfit).

This work has also shown that welding parameters very similar to those developed for the root and fill passes in titanium containers/4/ can be applied to Inconel containers. For titanium container designs employing a relatively thick wall (>6.4-mm), two capping passes were required for the final weld layer because weaving is generally not allowed in out-of-chamber titanium welding. However, by employing a weaved capping pass in the final weld layer, Inconel containers up to at least 7.2-mm thick can be welded successfully using a single pass per weld layer. This would greatly simplify seam tracking requirements when welding, since the seam tracker will only need to maintain the torch travel along the centerline of the weld groove.

In the development of GTAW procedures for titanium containers, the requirements for welding parameter optimization and control to accommodate changes in weld joint geometry and misfit and to maintain weld quality were evaluated. A similar evaluation could be done for Inconel containers.

4.2 Welding Position & Joint Design

The procedure developed in the present work could be used for the final closure of Inconel containers in the 2G welding position (i.e. container in the upright position). The 1G welding position is undesirable for welding since it would be necessary to tilt and rotate a loaded and unsealed container in the horizontal position.

The weld joint design incorporates an integral backing, which was also recommended for the titanium containers/4/. This joint design appears to be suitable in terms of tolerance to high/low misfit, in the ability to ensure good fusion, and strikes a balance between minimum weld volume and good sidewall fusion. Based on previous results in /4/, a high/low misfit (that is, the gap between the container wall and the top lid) of approximately 2-mm could likely be tolerated. Meeting the fit-up requirements of this joint will require some means of ensuring container roundness. This may include the use of clamping equipment, shrink-fitting, or machining of the container side wall (if extra material thickness is available).

Our present work has shown that sound Inconel 625 GTA welds could be made without the use of a backing gas shield. This is very important for nuclear fuel disposal container closure welding since the provision of backing gas coverage of the weld root is impractical. The use of a thick top lid and an integral backing support appears to be the most suitable technique for avoiding air contamination at the root.

4.3 Weld Quality and Mechanical Properties

In general, the quality of the Inconel 625 welds produced was acceptable. No discontinuities were discovered in the macroscopic cross-sections, nor could any be observed on the weld surface.

The mechanical properties of the weld joint were also acceptable. The tensile strength was comparable to the base metal and the fractures produced by tensile testing appeared to be ductile. No serious hardness variations were detected across the weld joint.

Although it is beyond the scope of the present investigation, the corrosion resistance of the weld joints is expected to be similar to that of the base plate. The addition of niobium to the alloy stabilizes Inconel 625 against sensitization during welding, preventing subsequent intergranular corrosion in the heat-affected zone of the base metal. Also, as shown in Table I, the welding filler wire is the same composition as the base metal, meaning that the corrosion resistance of the weld deposit itself should be similar to that of the general container.

5.0 CONCLUSIONS

5.1 We have demonstrated that sound gas-tungsten-arc welding procedures can be readily established for the final closure of thin-walled Inconel 625 nuclear fuel waste disposal containers in the 2G welding position (container upright).

5.2 The recommended design for the final closure joint of Inconel containers employs an integral backing to allow welding without the use of a backing gas shield.

5.3 We have shown that the root and fill-pass procedures developed for titanium containers can be successfully used for Inconel containers. Weaving can be allowed for the capping pass in Inconel welding, but is generally not recommended in titanium welding. With the use of a weaving capping pass, a single pass per weld layer technique can be used for the range of thicknesses considered for Inconel containers. This would greatly simplify seam tracking requirements.

6.0 RECOMMENDATIONS

6.1 Corrosion testing of welded joints should be conducted to assess their corrosion resistance in comparison to base metal.

6.2 Procedures for fitting the top lid into the rolled shell should be evaluated to ensure that tolerance limits of <2-mm plate offset can be met.

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TABLE I

CHEMICAL ANALYSIS* OF THE MATERIALS

(From Inco Alloys Certified Material Test Reports)*

Heat No	Ni	Cr	Mo	Nb + Ta	Fe	C	Al	Ti	Cu	Si	Mn	P	S	All Others
Base Plate NX4476AG	61.94	21.64	8.49	3.52	3.71	0.03	0.11	0.18	-	0.24	0.13	0.010	0.001	
Filler Wire NX4236AG	60.40	22.26	8.74	3.49	3.75	0.02	0.37	0.26	0.31	0.22	0.17	0.013	0.001	< 0.50

TABLE II

WELDING VARIABLES AND PARAMETERS

Base Metal : SB-443 (Inconel 625 plate)

Base Metal Thickness : 7.2-mm

Process : Automatic Pulsed Current GTAW (Dimetrics Gold Track II Pipe Welding System)

Filler Metal : ERNiCrMo-3 (SFA-5.14) 1.14-mm dia (0.045 in)

Shielding Gas : 100% Argon at 14.2 l/min (30 cfh) flow rate

Tungsten Electrode : EWTh-2 (SFA-5.12) 2.38-mm dia (3/32 in)

Position : 2G (weld horizontal)

Root Pass(#1)		Fill Passes (#2 & #3)	
High Pulse Current:	180 A	High Pulse Current:	180 A
Low Pulse Current:	80 A	Low Pulse Current:	80 A
Pulse Rate:	1 Hz	Pulse Rate:	1 Hz
Low Pulse Width:	50%	Low Pulse Width:	50%
Travel Speed:	1.0-mm/s	Travel Speed:	1.0-m/s
Voltage:	10.5 V	Voltage:	10.5 V
High Pulse Wire-Feed:	11-mm/s	High Pulse Wire-Feed:	13-mm/s
Low Pulse Wire-Feed:	6-mm/s	Low Pulse Wire-Feed:	8-mm/s

Capping Pass (#4)

Using "Sync Pulse Mode" the High Pulse Parameters are on only during the oscillator dwells.

High Pulse Current:	150 A	Top Dwell Time:	1.0 s
Low Pulse Current:	70 A	Excursion Rate:	1.0 s
Pulse Rate:	1 Hz	Bottom Dwell Time:	0.4 s
Low Pulse Width:	50%	Amplitude:	4.0-mm
Travel Speed:	0.8-mm/s		
Voltage:	11.0 V		
High Pulse Wire-Feed:	14-mm/s		
Low Pulse Wire-Feed:	6-m/s		

TABLE III

TENSILE TESTING RESULTS

Sample	Thickness (mm)	Width (mm)	Area (mm^2)	Ultimate Load (N)	Ultimate Tensile Strength	Failure Character	Failure Location
A	7.06	18.92	133.58	114,800	859 MPa (124,600 psi)	Ductile	Weld Metal
B	7.16	19.28	138.04	115,600	837 MPa (121,400 psi)	Ductile	Weld Metal

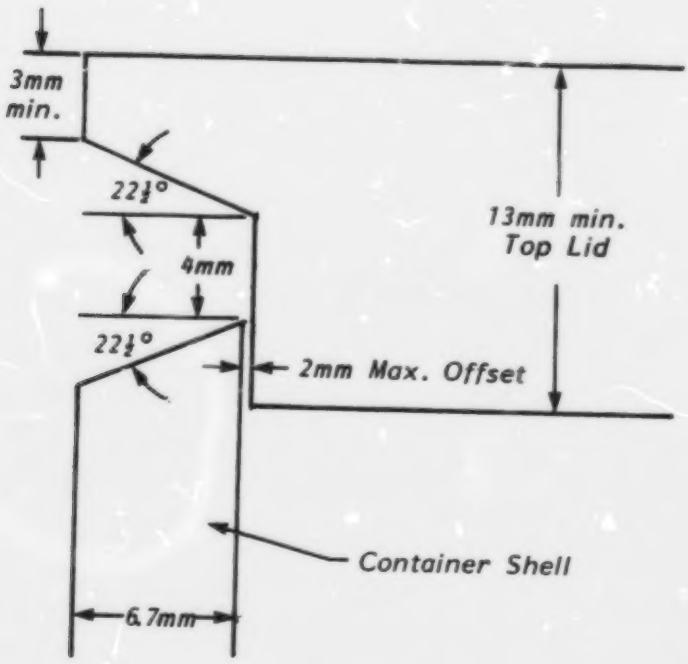

FIGURE 1

PROPOSED WELD JOINT DESIGN FOR THIN WALLED INCONEL 625 CONTAINERS (FINAL CLOSURE)

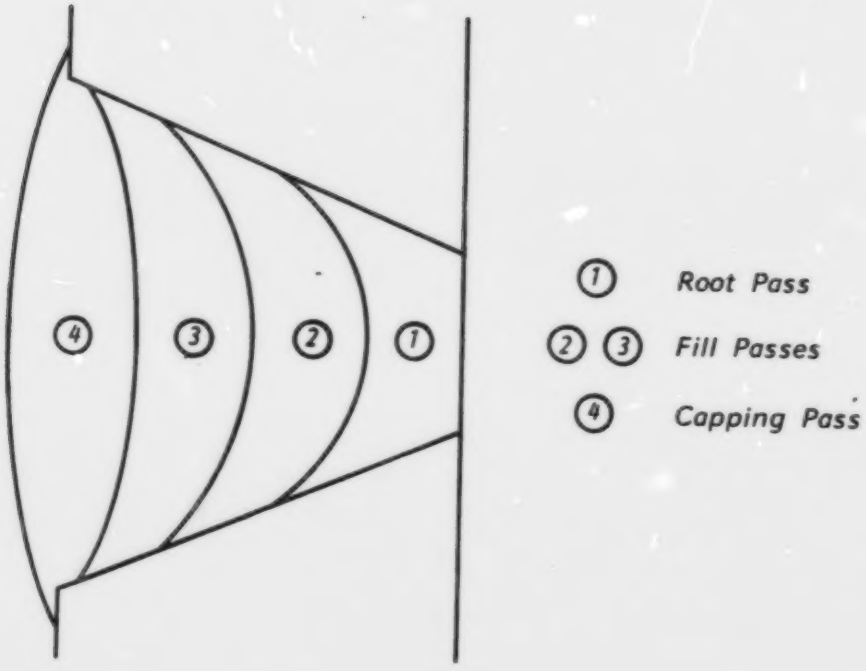

FIGURE 2

WELD PROCEDURE FILL PATTERN

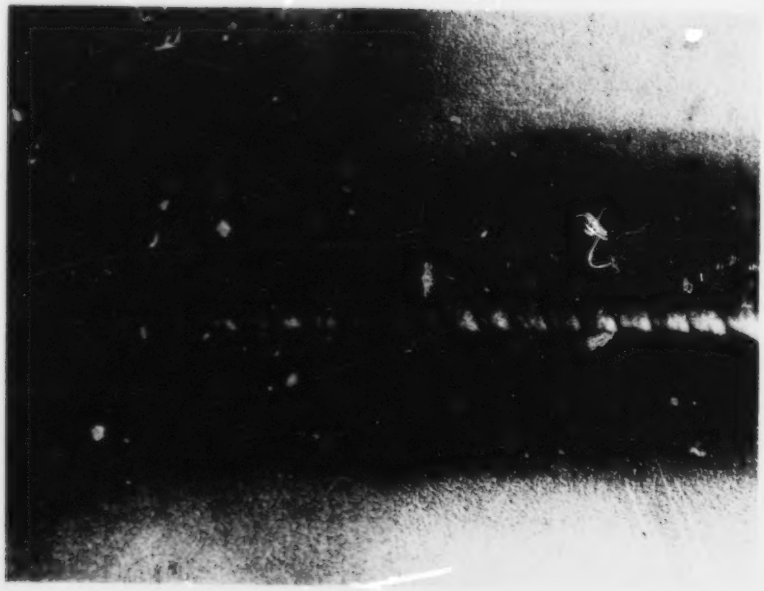

FIGURE 3
WELD SURFACE APPEARANCE (1.6 X)

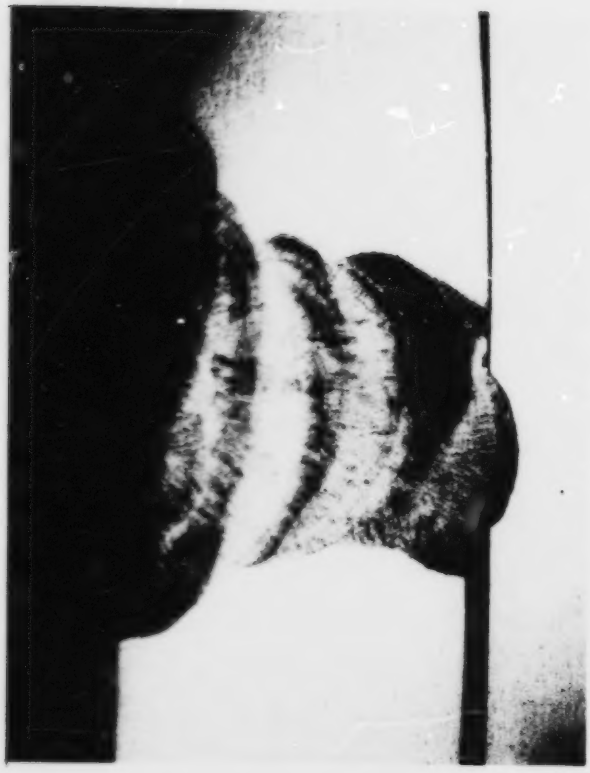

FIGURE 4
INCONEL GTAW WELD CROSS-SECTION (7.5 X)

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